LES Modeling of Aerosol and Drizzle Effects in Marine Stratocumulus

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Award #: N000149610687

LONG-TERM GOALS

The development and improvement of cloud microphysical and radiative parameterizations for use in cloud and numerical weather prediction models

OBJECTIVES

Study of marine stratocumulus cloud microphysical and radiative processes using a high-resolution large eddy simulation (LES) model with explicit microphysics. The objective of the project is to improve parameterizations of microphysical and radiative processes based on better understanding of interactions between these processes and boundary layer thermodynamics.

Towards this goal, we investigate:

1) Effect of Continental Polluted Air Mass (CPAM) outbreaks on marine stratocumulus cloud microstructure, drizzle, and thermodynamics
2) Performance of CIMMS cloud physics parameterization implemented into COAMPS
3) Effects of horizontal radiative transfer on cloud system evolution

APPROACH

The research is based on the LES model of boundary layer stratocumulus clouds with explicit formulation of aerosol and drop size-resolving microphysics. Observations obtained during ASTEX and ACE field projects have been used to simulate effects of continental polluted air mass outbreaks characterized by different properties of aerosol particles. The LES simulations, as well as 3D Monte Carlo radiative transfer model, were used to develop a method for retrieval of cloud radiative absorption.

WORK COMPLETED

The following tasks have been completed this year:

1. Investigation of the role of vertical distribution of CPAM aerosol concentration, as well as the CPAM aerosol predominant size, on marine stratocumulus cloud microphysical and thermodynamical structure.
2. Implementation of CIMMS stratiform cloud parameterization into COAMPS model
3. Evaluation of the role of horizontal radiative transfer on stratocumulus cloud evolution

Report Documentation Page					*Form Approved* *OMB No. 0704-0188*

1. REPORT DATE **30 SEP 2002**	2. REPORT TYPE	3. DATES COVERED **00-00-2002 to 00-00-2002**

4. TITLE AND SUBTITLE **LES Modeling of Aerosol and Drizzle Effects in Marine Stratocumulus**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **University of Oklahoma,,Norman,,OK, 73019**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR’S ACRONYM(S)
	11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT
The development and improvement of cloud microphysical and radiative parameterizations for use in cloud and numerical weather prediction models

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**7**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

RESULTS

1. The effects of CPAM parameters on cloud microstructure and drizzle

The oceanic atmosphere is significantly influenced by outbreaks of Continental Polluted Air Mass (CPAM) modified by anthropogenic or desert dust events. In a series of LES experiments we simulated different scenarios of the CPAM outbreaks focusing on the role of aerosol characteristic size and aerosol concentration vertical profile. Our main conclusions are as follows:

(1) Large and giant atmospheric particles (AP) descending into the cloud layer from the CPAM located above the inversion significantly enhance drizzle production leading to attenuated turbulence, widening of the entrainment zone, lifting of the cloud top, decoupling of the subcloud layer, and accelerated stratocumulus breakup. Fig. 1 illustrates these effects, in particular, is shows the enhanced drizzle production, breakup of a solid stratocumulus cloud layer into a system of convective cloud cells, and lowering of cloud top from 800 to 600 meters in the case of CPAM containing giant aerosol particles (right panel).

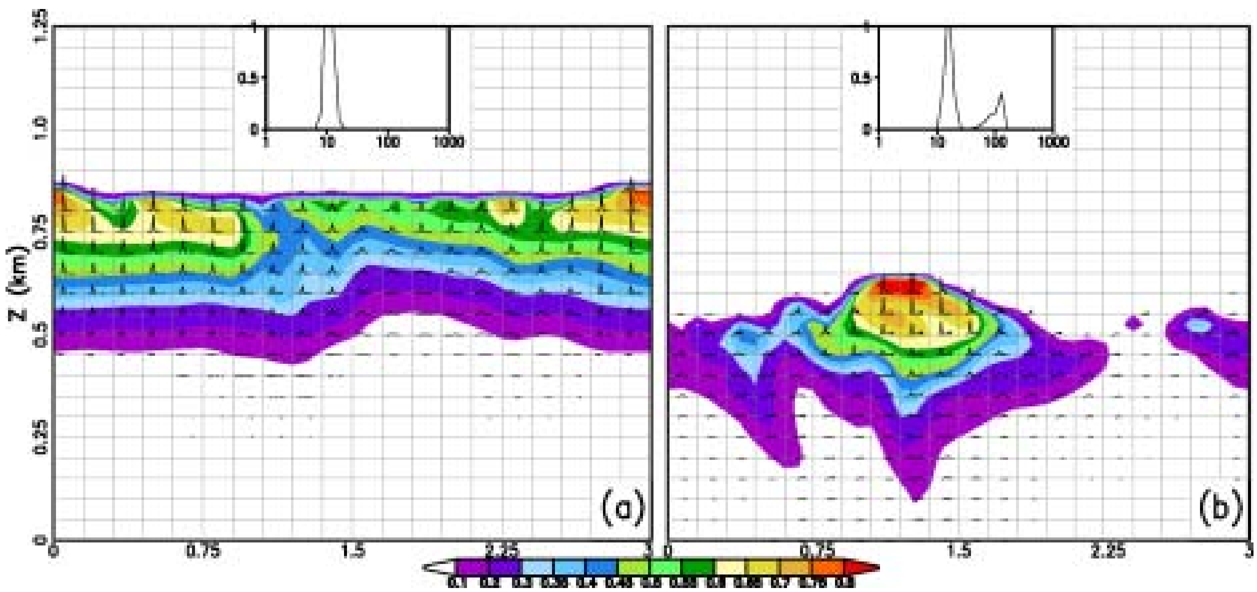

Fig. 1: Cloud droplet mass distributions in simulations of continental polluted air mass (CPAM) outbreaks. Left (right) panel depicts results of CPAM with a predominantly fine (large) particle mode. Color contours show liquid water content according to the color table. [Enhanced drizzle in the right panel results in cloud breakup and lowering of the cloud top by 200m.]

(2) In a marine air mass modified by continental polluted air mass that is characterized by predominantly fine mode AP, precipitation was suppressed. The suppression was less if the aerosol particles were seeded from the polluted layer above the inversion.

(3) The feedbacks between CPAM outbreaks and drizzle production, positive for continental air masses characterized by a large/giant particle mode and negative for a fine particle mode, were enhanced in the presence of a wind shear across the inversion.

The above conclusions implicate that in order to improve forecast of marine stratocumulus and/or quantify the aerosol indirect effect, it is important to take into account both the total aerosol load, as well as its vertical variation, the size of the dominant particles, and the wind shear across the inversion that controls the strength of the polluted CCN source.

2. Implementation of CIMMS stratiform cloud parameterization into COAMPS model

A case study of summer season PBL cloud has been simulated using COAMPS (U.S. Navy's Coupled Ocean/Atmosphere Mesoscale Prediction System). Results using a horizontal grid of 2 km show a strong diurnal cycle and fair agreement with SSM/I liquid water path. Using a more realistic CIMMS microphysical parameterization (KK in Fig. 2) increases in importance the finer the model resolution. When drizzle processes are included, the model produces a transition from a well mixed boundary layer topped by unbroken stratocumulus into a more potentially unstable, convective boundary layer regime (Fig. 2). The transition produced is the mesoscale model analogue to the drizzle-induced cloud breakup demonstrated in LES studies. The convective regime contains appreciable vertical velocity, linked to a weak decoupling of the cloud and subcloud layers, with the characteristic of an ensemble of cumulus updrafts. The results of the study demonstrate the potential of the CIMMS cloud physics parameterization in improving regional forecast of stratocumulus cloud systems.

3. The effects of horizontal radiative transfer on cloud system evolution

The study was conducted by linking the CIMMS LES model with Frank Evans's (the University of Colorado) SHDOM radiative transfer (RT) code. This coupling enabled us to evaluate the interactive effect on cloud system evolution of using multidimensional radiative transfer versus the typical one-dimensional plain-parallel treatment of radiation. A series of preliminary simulations of the interactive dynamics-radiative model were made in 2D. Results of lightly drizzling, unbroken stratocumulus cloud fields forced by longwave cloud top cooling show a 9% reduction in cloud top entrainment in the multidimensional RT case. Horizontal radiative fluxes are most pronounced in regions of cloud top variability and horizontal structure in liquid water content. The domain-mean peak cooling rates are slightly less in the multidimensional RT case, but more importantly the spatial structure of the radiative forcing differences is negatively correlated with the LES eddy structure, leading to a damping of the boundary layer energetics (see Fig. 3). Differences appear to be greater for a strongly drizzling, cloud breakup case, but the results are not as robust as for the unbroken cloud case, since a smaller domain size was used.

IMPACT

The improved parameterization of the physical processes in marine stratocumulus clouds will result in a more accurate numerical weather prediction for Navy operations. In particular, we expect an improved prediction of precipitating cloud layers, cloud optical and radiative parameters. The proposed approach for development of physical parameterizations using LES model data verified against observations is appropriate for other investigations.

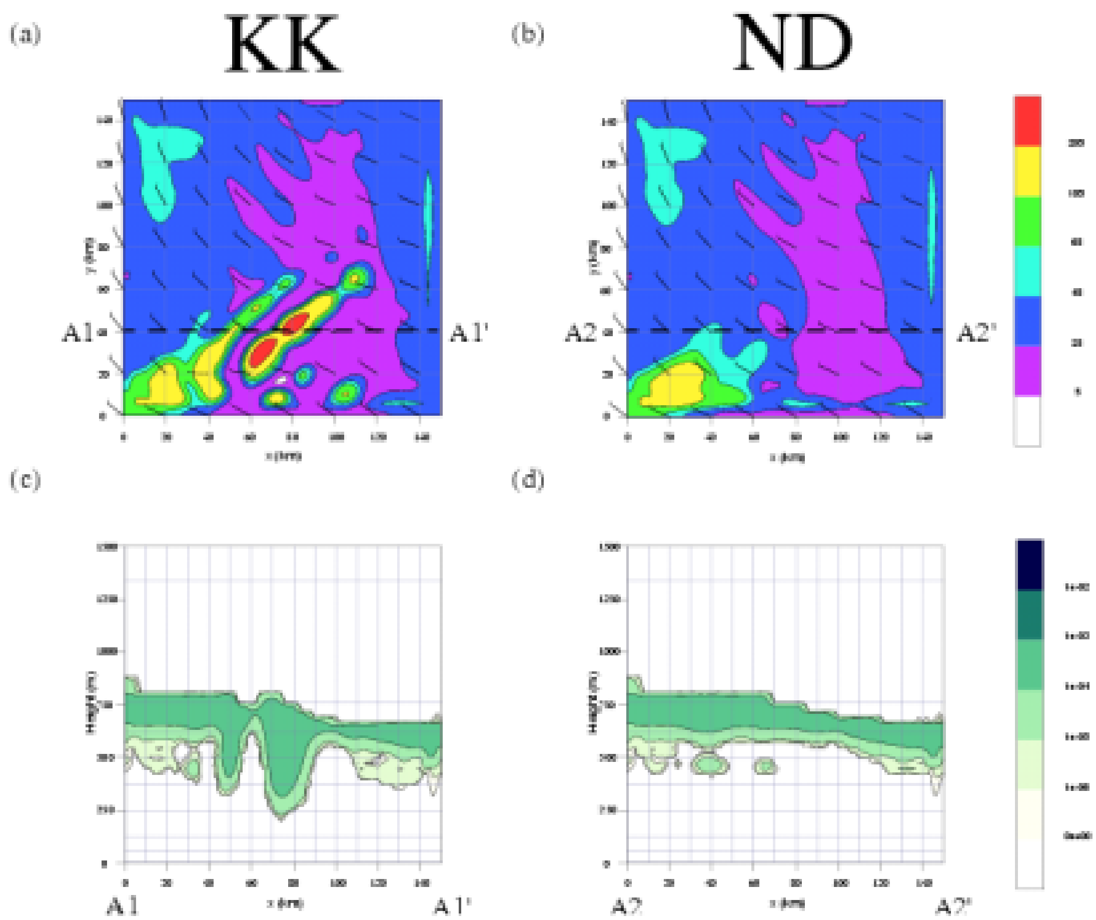

Fig. 2. Comparison of COAMPS simulation results from 18 UTC 25 July 1997 showing cloud system mesoscale structure. Liquid water path (LWP; g/m^2) and cloud water (Qc; kg/kg) are plotted for drizzling (KK) and non-drizzling (ND) experiments. (a) KK LWP; (b) ND LWP; (c) and (d) Vertical cross-section of Qc along lines A1-A1' and A2-A2' indicated in (a) and (b).

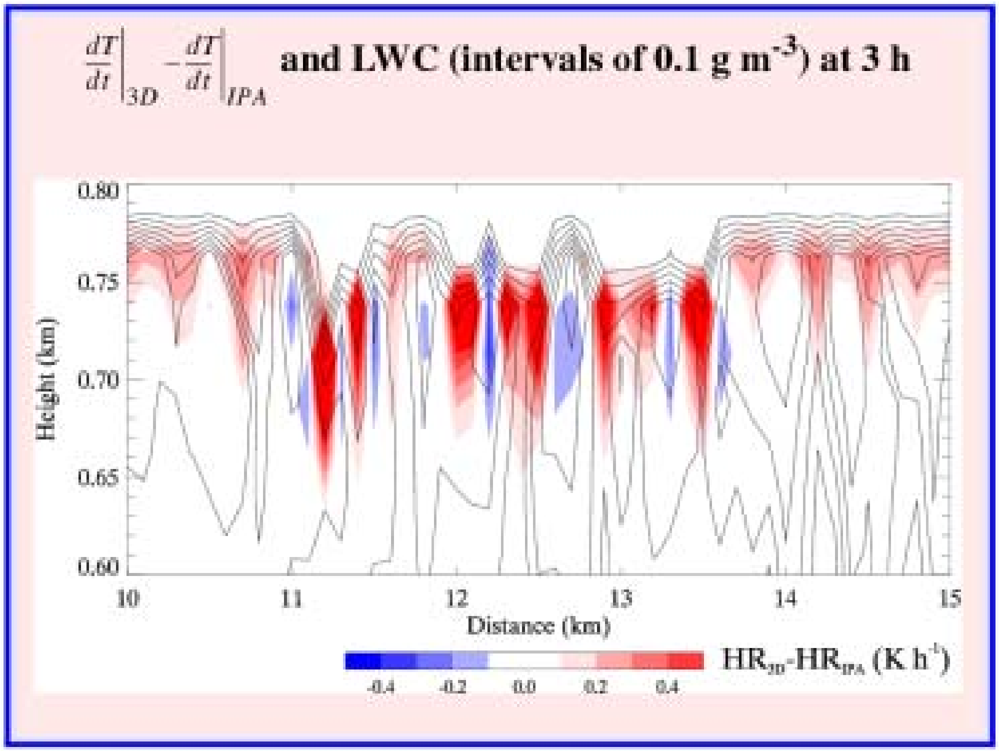

Fig. 3. Vertical cross section of stratocumulus cloud top. Contours are liquid water content (intervals of 0.1 g/kg). Filled color contours represent the difference in heating rates between multidimensional and IPA radiative transfer. [Positive values indicate less radiative forcing (reduced cloud top cooling) when horizontal radiative transfer is taken into account. Stronger forcing is associated with negative regions].

TRANSITIONS

The CIMMS drizzle parameterization is implemented into COAMPS model. Our results have been reported at three scientific meetings, published in refereed journals and conference proceedings (7 papers) and, thus, are well known to the scientific community.

RELATED PROJECTS

The study is aimed at development of physical parameterizations for cloud scale (LES) models. It is related to the ONR project "Remote sensing and prediction of the coastal marine boundary layer" (N00014-96-1-1112) awarded to the University of Oklahoma under the MURI program. The latter goal is to develop and implement physical parameterizations into mesoscale prediction models, in general, and COAMPS, in particular.

PUBLICATIONS

Kassianov, E. I. and Y.L. Kogan, 2002: Spectral dependence of radiative horizontal transport in stratocumulus clouds and its effect on near-IR absorption. *J. Geophys. Res.,* Accepted.

Kogan, Z., D. Mechem, and Y. Kogan, 2002: Variability of low stratus over ARM SGP site based on cloud radar observations and LES simulations. *Proceedings of the twelfth ARM Science Team Meeting*, San Petersburg, FL.

Lan, Y., Y. Kogan, and D. Mechem, 2002: The effect of continental air outbreaks on marine stratocumulus drizzle formation and cloud breakup. 11^{th} Conference on Cloud Physics. Ogden, Utah, 3-7 June 2002.

Mechem, D. B., Y. L. Kogan, and M. R. Poellot, 2002: Simulation of post-frontal boundary layers observed during the ARM 2000 Cloud IOP. *Proc. Of the Twelfth Atmospheric Radiation Measurement (ARM) Science Team Meeting*, 8-12 April 2002, St. Petersburg, FL

Mechem, D. B., Y. L. Kogan, and M. R. Poellot, 2002: Large eddy simulation of post-frontal boundary layers in the ARM 2000 Cloud IOP. *Preprints, 11^{th} Conference on Cloud Physics*, 3-7 June 2002, Ogden, UT.

Mechem, D. B., and Y. L. Kogan, 2002: Simulating the transition from drizzling marine stratocumulus to boundary layer cumulus clouds with a mesoscale model. In preparation for *Mon. Wea. Rev.*

Mechem, D. B., M. Ovtchinnikov, Y. L. Kogan, A. B. Davis, R. F. Cahalan, E. E. Takara, and R. G. Ellingson, 2002: Large eddy simulation of PBL stratocumulus: Comparison of multi-dimensional and IPA longwave radiative forcing. *Proc. Of the Twelfth Atmospheric Radiation Measurement (ARM) Science Team Meeting*, 8-12 April 2002, St. Petersburg, FL.

Mechem, D. B., M. Ovtchinnikov, Y. L. Kogan, A. B. Davis, R. F. Cahalan, E. E. Takara, and R. G. Ellingson, 2002: Multi-dimensional broadband IR radiative forcing of marine stratocumulus in a large eddy simulation model. *Preprints, 11^{th} Conference on Cloud Physics*, 3-7 June 2002, Ogden, UT, Amer. Meteor. Soc.

Mechem, D., and Y. Kogan, 2001: Representation of marine stratocumulus in regional forecast models: Role of subgrid inhomogeneity. *Fourth Conference on Coastal Atmospheric and Oceanic Prediction and Processes*, St. Petersburg, FL.